

EVIDENCE FOR A WARM DRY EARLY HOLOCENE
IN THE WESTERN SIERRA NEVADA OF CALIFORNIA:
POLLEN AND PLANT MACROFOSSIL ANALYSIS OF
DINKEY AND EXCHEQUER MEADOWS

OWEN K. DAVIS

Department of Geosciences, University of Arizona,
Tucson 85721

MICHAEL J. MORATTO

INFOTEC Research Incorporated, 19524 Hillside Drive,
Sonora, CA 95370

ABSTRACT

Pollen and plant macrofossil analysis and ten radiocarbon dates for the sediments of Dinkey and Exchequer Meadows provide a detailed record of environmental change in the western Sierra Nevada. The Dinkey Meadow sedimentary record is nearly 5000 yr long, and the Exchequer Meadow record reaches 13,500 yr B.P. The Exchequer Meadow pollen diagram is divided into an upper *Abies* zone (0–1870 yr B.P.), a *Pinus* zone (1870–7070 yr B.P.), and a basal *Artemisia* zone (7070–13,500 yr B.P.), which is subdivided into upper *Quercus* and lower Gramineae subzones at ca. 10,680 yr B.P. The *Artemisia* zone records more xeric vegetation than occurs west of the Sierra today, and it contains *Sequoiadendron* pollen, indicating temperatures little colder than today. The presence of spores of the dung fungus *Sporormiella* indicates that grazing animals were abundant during the Gramineae subzone. A period of maximum *Abies* percentages at Dinkey, Exchequer, and other Sierra Nevada sites may result from warm dry climate shortly after 1900 yr B.P.

California's remarkable diversity of vegetation types results in large part from its topographic and climatic heterogeneity. The forests of the Coast Ranges and Sierra Nevada are separated by the grasslands of the Central Valley, and deserts occupy the rainshadow of eastern California (Major 1977). An unexpected finding of paleoenvironmental research in California is that the coastal, interior, and rainshadow areas may have had different climatic histories. During the late-Pleistocene and early Holocene, coastal California and eastern California appear to have been moister than today, whereas the western Sierra was drier (Davis et al. 1985, Davis and Sellers 1987).

At the end of the Pleistocene, mesic pine forests of coastal California were replaced by oak woodlands. Adam and West (1983) interpret the higher *Pinus/Quercus* pollen ratios from Tule Lake (West 1982) and Clear Lake (Adam et al. 1981) as indicating greater moisture and cooler temperature before 7000 yr B.P. Plant macrofossil deposits also indicate increased moisture during the early Ho-

locene (Johnson 1977), and Bergquist (1977) reports *Picea* pollen, evidence for a cool-moist climate, in sediments older than 8400 ± 100 yr B.P. at Bolinas Lagoon, near San Francisco.

In contrast, vegetation of the western Sierra during the early Holocene resembled that found east of the Sierra today. *Artemisia* pollen is abundant in early Holocene sediments from Balsam Meadow (Davis et al. 1985), Swamp Lake (Batchelder 1980), Tulare Lake in the San Joaquin Valley of California (Atwater et al. 1986), and in lower King's Canyon (Cole 1983). Comparable *Artemisia* percentages have not been duplicated in any modern pollen samples from west of the Sierran crest (e.g., Adam 1967, West 1982, Davis et al. 1985, Anderson 1987). Such high *Artemisia* percentages have been found only in vegetation east of the crest, in the Sierran rain shadow (Adam 1967, Mehringer 1967, Anderson 1987). For such vegetation to occur on the west slope of the Sierra, the climate must have been drier than today. A glacial-age expansion of the Great Basin vegetation west of the Sierra is also documented by the abundance of *Sarcobatus* pollen in the Tulare Lake core (Atwater et al. 1986).

Early-Holocene aridity is documented at other sites of interior California by low lake levels and the expansion of xeric vegetation. At Gabbott Meadow Lake (1900 m, Mackey and Sullivan 1986) near the Sierra crest, oak percentages rise from $10,500 \pm 140$ to 7570 ± 100 yr B.P. and decline until 2270 ± 80 yr B.P., probably indicating an expansion of xeric oak woodland into pine forest. At Cedar Lake, Siskiyou Co., California (1743 m, West 1986), increased aridity during the early Holocene is indicated by elevated "TCT" (Taxaceae, Cupressaceae, Taxodiaceae) percentages from 7910 ± 120 to $10,180 \pm 150$ yr B.P. Most of the TCT pollen is probably derived from *Chamaecyparis lawsoniana*, which must have become established on the moraines surrounding the lake during a period of xeric climate. Because the lake is near the coast, this aridity conflicts with interpretations for other coastal sites; alternatively, the climatic history of the northern California coast may differ from that of more southern sites. However, Cedar Lake is leeward of the Siskiyou Mountains, which reach elevations over 2100 m. If ocean fogs are responsible for the early Holocene moisture in coastal sites, the Siskiyou rain shadow may have produced a climate like that of interior sites.

East of the Sierra Nevada in the Mojave Desert, the climate was wetter at the end of the last glaciation. Glacial Lake Mojave overflowed from ca. 15,500 to 10,500 yr B.P. (Wells et al. 1987), and Searles Lake overflowed ca. 11,000 yr B.P. (Smith and Street-Perrott 1983). Packrat middens from west of Las Vegas, Nevada, contain elevated percentages of mesic shrubs and succulents, indicators of increased summer precipitation from 12,000 to 8000 years ago (Spaulding and Graumlich 1986).

Because the Sierra Nevada was a major mountain range by 3 million yr B.P. (Chase and Wallace 1986), the trans-Sierra climatic contrast has existed throughout the Pleistocene. During the last glaciation the direction of prevailing winds was probably the same as today's. Coastal sand dunes of late glacial age record wind directions equivalent to modern (Johnson 1977). Pleistocene snowlines were 600 m higher in the rainshadow of the Sierra Nevada than in adjacent mountains. This greater elevation indicates moisture patterns similar to today's patterns (Porter et al. 1983).

Purpose of the study. Pollen analysis of Dinkey and Exchequer meadows, Fresno County, California, was undertaken to confirm the early Holocene aridity of the western Sierra Nevada. This verification is particularly important because areas to the west (coastal sites) and east (desert sites) of the western Sierra record greater moisture during the early Holocene. These regional differences in climatic change are in marked contrast to traditional climatic scenarios (Antevs 1948) that call for uniform climatic change throughout western North America: cool and moist before 7000 yr B.P., hot and dry from 7000 to 4500 yr B.P. (the Altithermal), and near modern climate from 4500 yr B.P. to present.

STUDY AREA

Regional climate. Precipitation in the western Sierra is dominated by the Aleutian low, which sends cyclonic storms eastward from the Pacific Ocean during winter months (Pyke 1972). Precipitation is greatest in January and February, with a distinct period of drought in June, July, and August when dry descending air from the Pacific high covers the Pacific coast and the juxtaposition of cold, dense oceanic air and warm continental air produce the stable Pacific air mass boundary (Mitchell 1976). As cyclonic storms move westward in winter, they cross the Sierra crest, losing most of their moisture before they enter the western Great Basin.

Present vegetation. The vegetation near Dinkey Meadow (37°N, 119°10'W, 1683 m) and Exchequer Meadow (37°N, 119°5'W, 2219 m) is characteristic of the upper (Exchequer) and lower (Dinkey) Sierran Montane Forest. *Pinus murrayana* is scattered over Dinkey Meadow, which is surrounded by a mixed stand of *Abies concolor*, *Pinus jeffreyi*, *Pinus lambertiana*, and *Calocedrus decurrens*. The coring site is covered with forbs, grasses, and scattered shrubs including *Vaccinium occidentale*, *Polygonum amphibium*, *Scirpus* sp., and *Poa* spp. in wet places; and *Ribes roezlii*, *Ribes nevadense*, *Symphoricarpos parishii*, *Ceanothus leucodermis*, *Viola macloskeyi*, and *Apocynum pumilum* on the uplands.

The coring site at Exchequer meadow is wetter and is dominated

by *Carex* spp. and *Scirpus* spp. Scattered *Pinus murrayana* grow on the meadow, which is surrounded by *Pinus jeffreyi* and occasional *Abies magnifica*. *Ribes roezlii* and *Ribes nevadense* are common understory plants in the forest.

Glacial deposits. The western Sierra was glaciated extensively during the late Pleistocene, and Matthes (1960) mapped glacial deposits nearly down to the elevation of Dinkey Meadow ca. 1700 m. Although we know of no detailed maps of glacial deposits for the area, Matthes' (1960) maps indicate that Dinkey Meadow was beyond the terminal moraine, and Exchequer Meadow was adjacent to, but not covered by, the Dinkey Creek glacial lobe (Fig. 1).

METHODS

The sediments of Dinkey and Exchequer Meadows were cored on September 1, 1985. The wettest portions of the meadows were chosen for coring to avoid oxidation or loss of sediment due to drying.

Sampling techniques. At Exchequer Meadow the upper 124 cm of sediment was collected with a 5 cm diameter square rod piston sampler (Wright 1967), and the lower sediment was cored with a 2.5 cm diameter Dachnowsky corer (Faegri and Iversen 1975) to 399 cm depth. The entire 300 cm Dinkey Meadow core was recovered with the piston sampler except for the interval from 210 to 230 cm, which was recovered with the Dachnowsky.

The cores were wrapped in plastic film and aluminum foil, and were stored at 1°C prior to sampling. Volcanic ash layers were submitted to Andrei Sarna-Wojcicki, U.S. Geological Survey, Menlo Park, California, for identification. Radiocarbon samples were submitted to Beta Analytic, Coral Gables, Florida.

Radiocarbon dates. All ten radiocarbon samples (Figs. 2 and 3) were adjusted for $^{13}\text{C}/^{12}\text{C}$ fractionation, and samples Beta-16113 and Beta-17185 from Exchequer Meadow were given extended counting times because they contained small amounts (0.20 and 0.35 g, respectively) of carbon. For Dinkey Meadow the sedimentation rate changed from 0.08 cm yr^{-1} to a slower 0.05 cm yr^{-1} below 150 cm (Fig. 2). For Exchequer Meadow the sedimentation rate was nearly constant (0.03 cm yr^{-1}) from the surface to the base of the core (Fig. 3).

Pollen extraction. Pollen extraction followed standard procedures (Faegri and Iversen 1975). The samples (volume 1 cm^3) were placed in 10% HCl and *Lycopodium* tracers were added to permit calculation of pollen concentration. After screening, the samples were treated with concentrated HCl and left overnight in 40% HF to remove carbonates and silicates. The samples were acetolyzed to

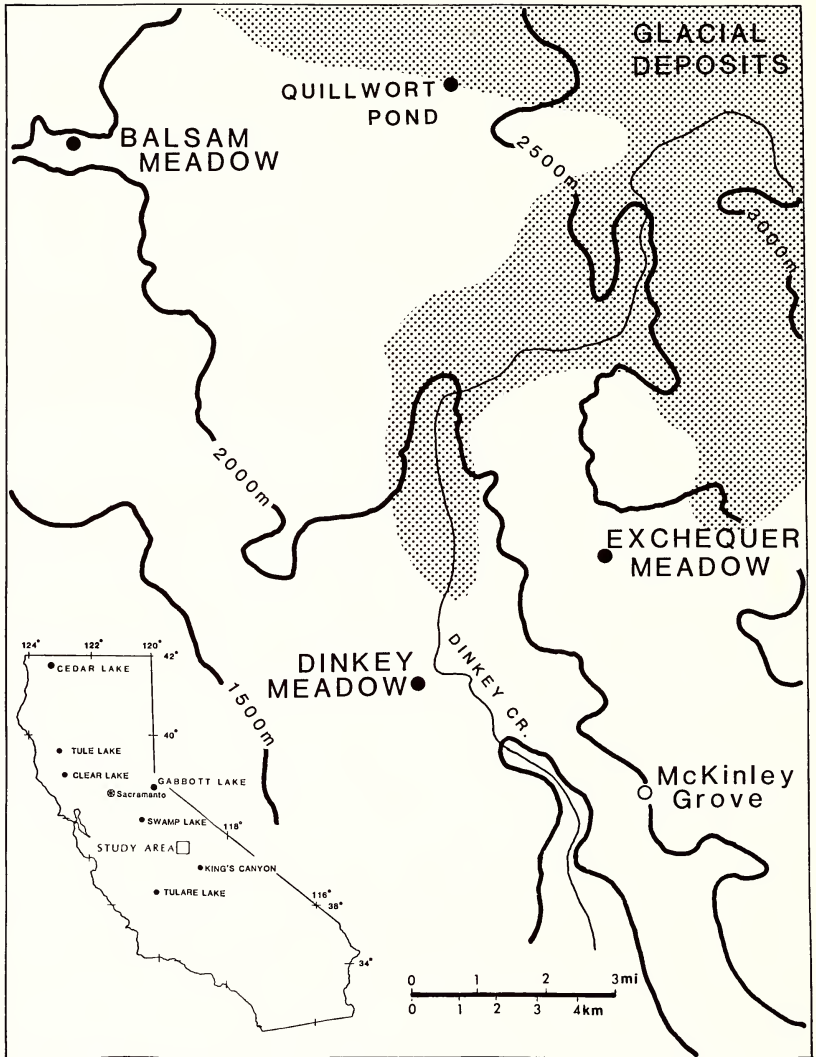


FIG. 1. Map of Dinkey and Exchequer Meadows area showing extent of late-Pleistocene Glaciation (stippled pattern). Inset shows location of California sites mentioned in text.

remove cellulose and similar organic compounds, and treated with 10% KOH to remove humates. After staining, the samples were transferred to glycerin.

Pollen identifications were based on the reference collection and

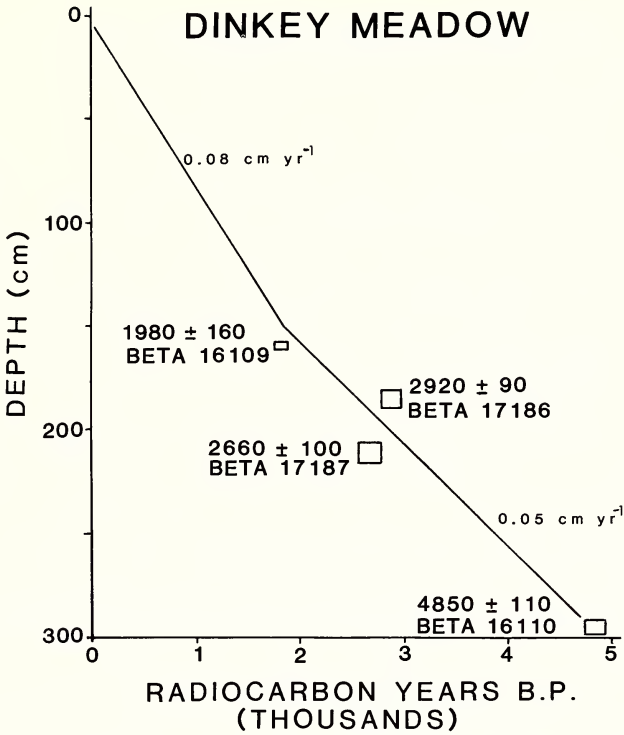


FIG. 2. Graph of Dinkey Meadow radiocarbon dates versus sediment depth. Solid line shows least squares regression of dates on sediment depth below 150 cm; above this depth it is connected directly to the surface. Height of squares is sample interval, width is date \pm one standard deviation.

library at the University of Arizona Palynology Laboratory. The pollen sum (divisor for percentage calculations) does not include aquatics; e.g., *Salix* or *Cyperaceae*, or spores. The following notes apply to the types shown on the pollen diagrams (Figs. 4 and 5): *Cupressaceae* may include some *Taxaceae* and *Taxodiaceae* except *Sequoiadendron*. *Ericaceae* includes mostly *Arctostaphylos* but at least one other type was seen. "Other Compositae" includes all pollen of that family excluding *Ambrosia*, *Artemisia*, *Cirsium*, and *Liguliflorae*.

Plant macrofossils. The sediment from both sites was suspended in water and screened to remove fine inorganic particles. Identifiable remains (seeds, needles, and large pieces of wood) were removed from the matrix under 7–45 \times magnification. Conifer needles were sectioned to permit species identification, and the abundance of

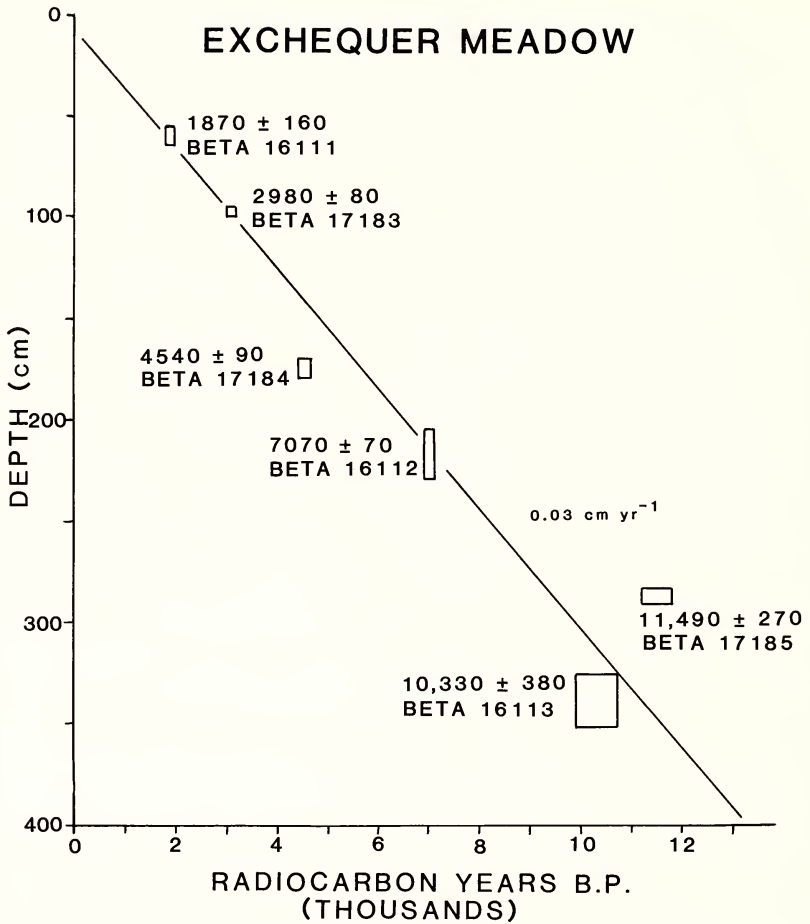


FIG. 3. Graph of Exchequer Meadow radiocarbon dates versus sediment depth. Solid line shows least squares regression of dates on sediment depth. Height of squares is sample interval, width is date \pm one standard deviation.

charcoal was noted on a scale of zero (absence) to four (very abundant).

RESULTS

The Dinkey Meadow sediments are yellowish brown (10YR 5/4, Munsell color) to very dark gray (5YR 3/1) peat down to 69 cm; and dark gray (10YR 4/1) medium sand to the base of the core. A volcanic ash layer is present at 39–40 cm. Exchequer Meadow sediments are less homogeneous. They are primarily peat down to 101

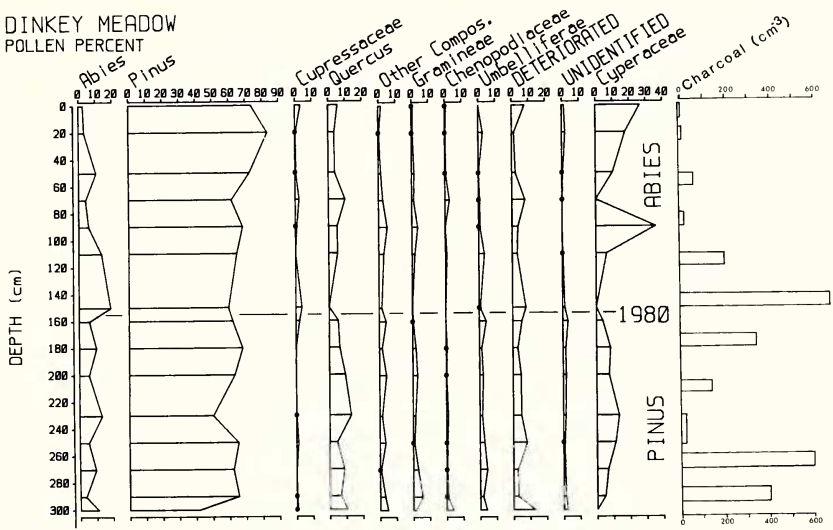


FIG. 4. Dinkey Meadow pollen diagram for abundant pollen types plotted versus sample depth. Dots are for percentages less than 2%. Cyperaceae and other aquatics are outside the pollen sum, *Pinus* is in the sum. Pollen zones and ages of boundaries shown on right. Vertical width of charcoal histograms shows width of sediment sample interval.

cm, interbedded sand and peat to 290 cm, and alternating fine and coarse sand down to 399 cm. Two volcanic ashes are present at Exchequer Meadow: one at 50–54 cm; the other at 169–170 cm; The 54 cm Exchequer Meadow ash, the only one suitable for identification, was identified as a “young Inyo Crater Ash.”

Dinkey Meadow. The Dinkey Meadow pollen diagram (Fig. 4) shows relatively little change, which is not surprising given its relatively brief (<5000 yr) record. *Pinus* is the most abundant pollen type (50–83%), followed by *Abies* (4–19%) and *Quercus* (0–13%). The percentages of *Abies* are lower and the percentages of *Quercus* are higher than at Balsam Meadow, which is consistent with the lower elevation (2040 vs. 1683 m) of Dinkey Meadow. The age of maximum *Abies* pollen percentages (Fig. 4) at Dinkey Meadow (1980 ± 160) is very close to estimated age of maximum *Abies* percentages (1710 yr B.P.) at Balsam Meadow.

The plant macrofossils from Dinkey Meadow (Table 1) provide additional data for paleoenvironmental reconstructions. All of the conifer species now at the site are present as plant macrofossils. *Pinus murrayana* needles are the most abundant macrofossil, but other conifers are absent above 100 cm. The sediments from 100–170 cm, which contain maximum *Abies* pollen percentages, contain

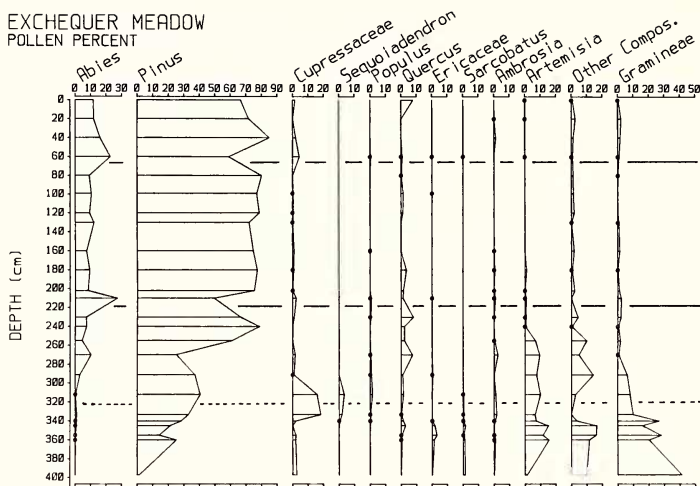


FIG. 5. Exchequer Meadow pollen diagram for abundant pollen types plotted versus sample depth. Dots are for percentages less than 2%. Cyperaceae and other aquatics are outside the pollen sum, *Pinus* is in the sum. Pollen zones and ages of boundaries shown on right. Vertical width of charcoal histograms shows width of sediment sample interval.

both *Abies concolor* and *Abies magnifica* needles, so both species could have contributed to the *Abies* pollen maximum. The *Abies magnifica* needles in the 110–120 cm sample, however, are the only remains of this species in the core. Charcoal abundance (Fig. 4) shows two peaks: one at 170–180 cm (2365 yr B.P.) just before maximum *Abies* pollen percentages, and the other at 260–270 cm (ca. 4180 yr B.P.). This trend in charcoal concentration is similar to that at Balsam Meadow (Davis et al. 1985).

Exchequer Meadow. The pollen zones for Exchequer Meadow (Fig. 5) are the same as those for Balsam Meadow (Davis et al. 1985) demonstrating the regional nature of the vegetation change, but the beginning of the *Abies* zone is later (1870 ± 60 yr B.P.) than at Balsam Meadow (3000 yr B.P.). The age of maximum fir percentages, however, is nearly the same at Exchequer (1870 ± 70), Dinkey Meadow (1980 ± 160) and Balsam Meadow (1710 yr B.P.). The boundary between the *Pinus* and *Artemisia* zones at 7070 ± 70 yr B.P. is synchronous with this transition at Balsam Meadow, but the basal *Artemisia* zone is longer, and is subdivided into upper *Quercus* and lower Gramineae subzones at ca. 10,680 yr B.P. In the Gramineae subzone percentages of *Sequoiadendron*, Gramineae, *Cas-tilleja*, and Cruciferae are greater than any at Balsam Meadow.

The diversity and concentration of plant macrofossils at Exchequer Meadow is less than at Dinkey Meadow. Sedge (*Carex*) remains

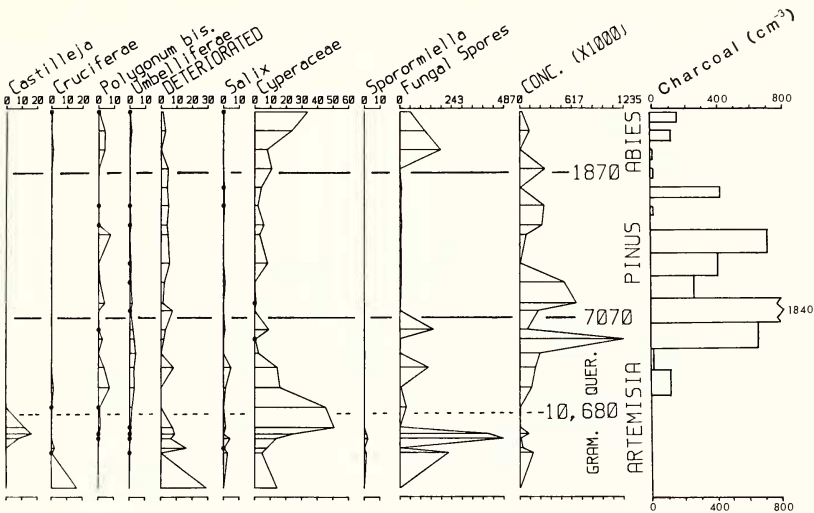


FIG. 5. Continued.

are the most abundant type. The *Abies* needles were preserved too poorly to identify to species, but *Abies* sp. and *Pinus murrayana* remains were present in surface sediment (Table 2). Charcoal fragments reach peak abundances at 80–90 cm (2740 yr B.P.), 124–129 cm (4140 yr B.P.), and 199–244 cm (7350 yr B.P.), a sequence similar to that at Balsam Meadow.

DISCUSSION

Paleoclimatology. An *Abies* pollen maximum shortly after 1900 yr B.P. is present at all three sites we have studied in the area. This event follows the general initiation of meadow development in the western Sierra (Wood 1975) that accompanied the beginning of Neoglacial cooling ca. 3000 years ago. Nineteen hundred yr B.P. is recognized as an interval of glacier retreat within the Neoglacial in western North America (Porter and Denton 1967), but Scuderi (1984) states that glaciers in the high Sierra Nevada may have advanced at this time (1850 yr B.P.). Nineteen hundred yr B.P. falls between periods of cool moist climate recorded in the growth of bristlecone pine in the White Mountains of eastern California (LaMarche 1978).

At Balsam and Dinkey Meadows macrofossils of *Abies concolor* and *A. magnifica* are present during the *Abies* pollen maximum (Table 2, Fig. 5). Today, these species do not grow on the bogs. Both white and red fir are characteristic of relatively dry slopes (Munz 1959), so the invasion of the meadows 1900 yr B.P. may indicate a period of warm, dry climate when the bogs dried. The Exchequer Meadow core was taken near the edge of the meadow; consequently,

TABLE 1. DINKEY MEADOW PLANT MACROFOSSIL CONCENTRATIONS (100 cm⁻³).

Sample interval	0-10	17-27	50-60	80-90	110-120	140-150	170-180	205-215	232-256	260-270	285-295
<i>Abies magnifica</i> needles	0	0	0	0	3	0	0	0	0	0	0
<i>Abies concolor</i> needles	0	0	0	0	0	0	3	0	0	3	0
<i>Abies</i> undif. needles	0	0	0	0	1	0	0	0	0	4	1
cf. <i>Calocedrus</i> bract	0	0	0	0	2	0	0	0	0	0	0
<i>Pinus jeffreyi</i> seed	0	0	0	0	0	0	0	0	0	0	1
<i>P. lambertiana</i> needle	0	0	0	0	1	0	0	0	0	0	0
<i>P. murrayana</i> needles	12	4	0	0	6	4	0	0	1	140	323
<i>P. murrayana</i> cones	0	0	0	0	0	0	1	0	1	1	3
<i>P. murrayana</i> seed	0	0	0	0	1	0	0	0	0	0	0
<i>Sambucus</i> seed	0	0	0	0	0	0	0	0	0	1	0
<i>Viola</i> seeds	0	1	0	0	0	0	2	0	0	29	0
<i>Carex</i> lenticular	20	0	1	0	1	0	2	1	0	6	0
<i>Carex</i> trigonous	1	0	0	1	1	0	0	0	0	6	3
<i>Potamogeton</i> seeds	0	0	2	0	5	0	0	0	0	1	0
Unidentified seeds	0	0	0	0	0	0	2	2	0	0	1
<i>Isoetes</i> megaspore	0	0	0	0	1	0	0	0	0	0	0
Unidentified wood	0	0	8	12	5	6	3	2	3	74	102
Charcoal >0.5 mm	5	16	58	19	180	683	365	132	23	589	372
Moss stems	1	0	0	0	0	0	0	0	0	0	0
Insect parts	6	0	0	1	0	0	1	0	0	0	1
Fecal pellets	0	0	0	0	6	12	0	9	0	9	2
Volume sediment cc	100	100	100	100	100	100	100	100	231	100	100

its surface sediment contains fir macrofossils. During the fir pollen maximum, sedge pollen percentages are low at Dinkey Meadow (Fig. 4), and sedge macrofossils are absent in Exchequer Meadow sediments (Table 2), perhaps indicating meadow desiccation.

A date of 1920 ± 50 yr B.P. (A-4428) at 64–70 cm marks a transition from inorganic to organic sediments at Quillwort Pond (Fig. 1). *Isoetes* megaspores are present throughout the 1 m core, but below 70 cm pebbles are abundant and plant macrofossils are absent. Above 70 cm *Potamogeton* and *Carex* are common, and conifer needles and seeds are abundant (up to 12 *Abies* needles cm^{-3}). Thus, the date marks the beginning of encroachment of trees and emergent aquatics into the Quillwort Pond basin.

Sites at higher elevation do not consistently show the *Abies* pollen maximum (Anderson 1987), so its importance may be limited to low elevation sites (below 2400 m?) where precipitation is less.

An "early Holocene Xerothermic." The classical climatic sequence for western North America calls for greatest temperatures and lowest moisture 7000–4500 yr B.P. during the "Altithermal" of Ernst Antevs (1948). This chronology was never accepted universally (Aschman 1957, Martin 1963), and many authors (Kearney and Luckman 1983, Ritchie et al. 1983, Hebda and Mathewes 1984, Davis et al. 1985, 1986, Elias 1985, Vance 1985) have found evidence for a much earlier thermal maximum centered ca. 10,000–8000 yr B.P., before the beginning of the classical Altithermal.

Many of the studies documenting the "early Holocene Xerothermic" (a phrase proposed by Hebda and Mathewes 1984), have been of sites at high elevation (Kearney and Luckman 1983, Elias 1985) or at high latitudes (Ritchie et al. 1983) where summer temperature controls the position of tree line. Due to the changing relationship of the perihelion and the summer solstice, insolation during summer months (June, July, August) was greatest in the northern hemisphere prior to 7000 yr (Davis et al. 1986). Although the actual change in insolation is small, atmospheric circulation is very sensitive to even small changes in insolation. General Circulation Models (e.g., Sellers 1984, Kutzbach and Guetter 1986) indicate summer temperature 9000 yr B.P. were 1–2° C warmer than today.

Previous paleoenvironmental studies in the western Sierra Nevada have demonstrated maximum aridity in the early Holocene ca. 7000–10,000 yr B.P. (Davis et al. 1985). The data from Exchequer Meadow corroborate this finding, providing support for the contrast between western Sierra climate and that of regions to the west and east. The early-Holocene sediments from Exchequer Meadow also contain the pollen of species that are today near their upper-elevational limits, indicating that temperatures were not much colder than today, thereby supporting the findings of Kearney and Luckman (1983), Ritchie et al. (1983), and Elias (1985) based on the position of upper treeline.

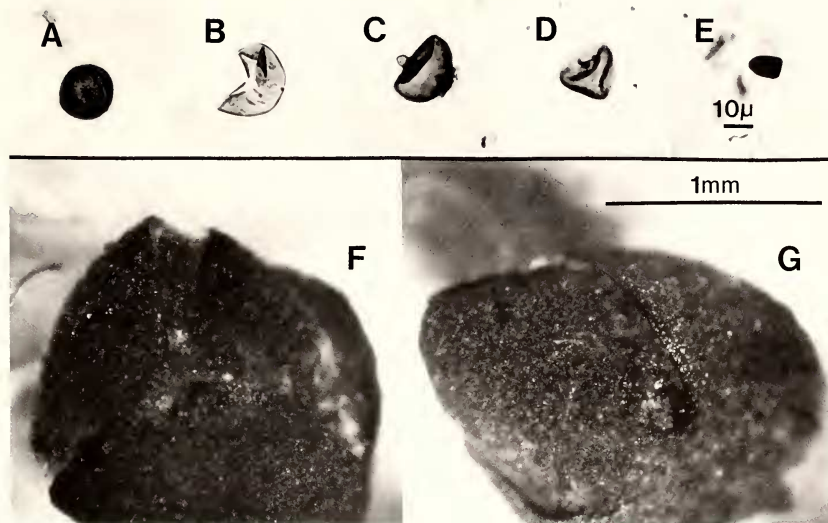


FIG. 6. A–D. Pollen from Exchequer Meadow, 312 cm *Artemisia* (A), Cupressaceae (B), *Sequoiadendron* (C–D); E. *Sporormiella* spore (Exchequer Meadow, 345 cm); F–G. terminal bud of *Calocedrus* or *Juniperus* (Exchequer Meadow, 274–299 cm).

At Exchequer Meadow, *Sequoiadendron* pollen is present from 312–340 cm and a cf. *Calocedrus* or *Juniperus* macrofossil is present at 274–299 cm (Fig. 6). Both *Sequoiadendron* and *Calocedrus* (now at 1400–2560 m and 730–2500 m respectively, Munz 1959, 1968) would be near their upper elevational limit at Exchequer Meadow (2219 m), and neither are present there today. The nearest *Sequoiadendron* grove to Exchequer Meadow today is the McKinley grove, 5 km south at 1951 m elevation (Fig. 1).

A series of environmental factors influence the distributions of plant taxa. Soil moisture and fire frequency are particularly important for the regeneration of *Sequoiadendron*. But in general, the upper elevational limits of plants are set by temperature (Daubenmire 1943). For these species to have been present near their current upper-elevation limits during the early Holocene, temperatures could not have been much colder than today.

Cole (1983) has documented the presence of *Sequoiadendron* pollen and *Calocedrus* macrofossils from 14,190 to over 45,000 yr B.P. in packrat middens from 980 to 1280 m elevation in Kings Canyon (Fig. 1). It appears that these species also were more widespread at low elevation during the late-glacial and early Holocene.

Prior to the expansion of *Sequoiadendron*, the vegetation near Exchequer meadow probably resembled Cruciferae-dominated al-

pine grassland that today occurs on dry open areas with raw soil (Major and Taylor 1977, p. 629). The dearth of tree pollen and abundance of herb pollen, particularly *Castilleja* and Cruciferae (Fig. 5) indicate alpine vegetation. We infer a rapid climatic warming ca. 11,000 yr B.P.

The absence of spores of the dung fungus *Sporormiella* in sediments younger than ca. 11,000 yr B.P. at Exchequer Meadow may date the extinction of the Rancholabrean megafauna in the western Sierra. The spores are not present in Holocene sediments, but are abundant (2.3%, 32 grains $\text{cm}^{-2} \text{yr}^{-1}$) in sediments below 340 cm (Fig. 5) equivalent to an age of 11,600 yr B.P. (Fig. 3). *Sporormiella* spores (Fig. 6) are abundant in modern sediments only where introduced grazing animals are plentiful, and they are even more profuse in sediments older than 11,000 yr B.P. in several sites (Davis 1987). The spores are linked directly to extinct animals by their presence in mammoth dung (Davis et al. 1984). Although *Sporormiella* spores are not restricted to extinct animals, their presence in late-Pleistocene sediments at Exchequer Meadow and other sites appears to record a declining abundance of grazing animals at the end of the Pleistocene.

CONCLUSIONS

The pollen and macrofossil records from Exchequer Meadow indicate vegetation during the early Holocene resembling that found east of the Sierra Nevada today. These records corroborate earlier findings of aridity in the western Sierra at a time when areas to the west and east were relatively moist, concurrent with the extinction of Pleistocene megafauna in the area. Modern climatic contrasts between coastal, interior, and rainshadow regions play an important role in the vegetational differences among these areas. Paleovegetation data from Exchequer Meadow and other sites indicate different climatic and vegetational histories for these areas during the late Quaternary. These paleoclimatic differences also may have played a role in the differentiation of these vegetation types.

ACKNOWLEDGMENTS

Financial support for the analysis of Dinkey Meadow and Exchequer Meadow sediments was provided by Kings River Conservation District through Clinton Blount, Theodoratus Cultural Research Inc., Fair Oaks, California. Pollen from Dinkey and Exchequer Meadows was counted by R. S. Anderson, O. K. Davis, K. L. Moore, and D. S. Shafer. R. S. Anderson analyzed plant macrofossils from Dinkey Meadow. O. K. Davis and J. A. Kailey analyzed plant macrofossils from Exchequer Meadow. We thank C. T. Mason, curator, University of Arizona Herbarium for specimens used in the identification of plant macrofossils.

LITERATURE CITED

- ADAM, D. P. 1967. Late-Pleistocene and Recent palynology in the central Sierra Nevada, California. In E. J. Cushing and H. E. Wright, Jr., eds., Quaternary

- paleoecology, p. 275–301. International Union for Quaternary Research. Vol. 7. Yale Univ. Press, New Haven, CT.
- , R. BYRNE, and E. LUTHER. 1981. A late Pleistocene pollen record from Laguna de las Trancas, northern coastal Santa Cruz County, California. *Madroño* 28:253–272.
- and G. J. WEST. 1983. Temperature and precipitation estimates through the last glacial cycle from Clear Lake, California, pollen data. *Science* 219:168–170.
- ANDERSON, R. S. 1987. Late-Quaternary environments of the Sierra Nevada, California. Ph.D. dissertation, Univ. Arizona, Tucson.
- ANTEVS, E. V. 1948. The Great Basin, with emphasis on glacial and postglacial times. *Bull. Univ. Utah* 38:168–191.
- ASCHMAN, H. 1957. Great Basin climates in relation to human occupation. *Rep. Univ. Calif. Archeol. Surv.* 42:23–40.
- ATWATER, B. F., et al. 1986. A fan dam for Tulare Lake, California, and implications for the Wisconsin glacial history of the Sierra Nevada. *Geol. Soc. Amer. Bull.* 97:97–109.
- BATCHELDER, G. L. 1980. A late Wisconsinan and early Holocene lacustrine stratigraphy and pollen record from the west slope of the Sierra Nevada, California. *Sixth Annual Amer. Quaternary Assoc., Abstr. with Programs* 13.
- BERGQUIST, J. R. 1977. Depositional history and fault-related studies, Bolinas Lagoon, California. Ph.D. dissertation, Stanford Univ., Stanford, CA.
- CHASE, C. G. and T. C. WALLACE. 1986. Uplift of the Sierra Nevada of California. *Geology* 14:730–733.
- COLE, K. L. 1983. Late Pleistocene vegetation of Kings Canyon, Sierra Nevada, California. *Quaternary Res.* 19:117–129.
- DAUBENMIRE, R. 1943. Vegetation zonation in the Rocky Mountains. *Bot. Rev.* 9: 325–393.
- DAVIS, O. K. 1986. Late-Quaternary environments of the western Sierra: pollen and plant macrofossil analysis of Dinkey and Exchequer Meadows. Report distributed by Theodoratus Cultural Research Inc., Fair Oaks, CA.
- . 1987. Spores of the dung fungus *Sporormiella*: increased abundance in historic sediments and before Pleistocene megafaunal extinction. *Quaternary Res.* 28:289–294.
- , L. AGENBROAD, P. S. MARTIN, and J. I. MEAD. 1984. The Pleistocene dung blanket of Bechan Cave, Utah. *Spec. Publ. Carnegie Mus. Nat. Hist.* 8:267–282.
- , R. S. ANDERSON, P. L. FALL, M. K. O'ROURKE, and R. S. THOMPSON. 1985. Palynological evidence for early Holocene aridity in the southern Sierra Nevada, California. *Quaternary Res.* 24:322–332.
- and W. D. SELLERS. 1987. Contrasting climatic histories for western North America during the late glacial and early Holocene. *Current Research in the Pleistocene.* 4:87–89.
- , J. C. SHEPPARD, and S. ROBERTSON. 1986. Contrasting climatic histories for the Snake River Plain result from multiple thermal maxima. *Quaternary Res.* 26:321–339.
- DORN, R. I., B. D. TURRIN, A. J. T. JULL, T. W. LINICK, and D. J. DONAHUE. 1986. Radiocarbon age for Tioga moraines of Pine Creek, eastern Sierra Nevada in California, and paleoclimatic implications. *Quaternary Res.* 28:38–49.
- ELIAS, S. A. 1985. Paleoenvironmental interpretations of Holocene insect fossil assemblages for four high-altitude sites in the Front Range, Colorado, U.S.A. *Arctic Alpine Res.* 17:31–48.
- FAEGRI, K. and J. IVERSEN. 1975. *Textbook of pollen analysis.* Hafner Press, NY.
- HEBDA, R. J. and R. W. MATHEWES. 1984. Holocene history of cedar and native Indian cultures of the North American Pacific coast. *Science* 255:711–712.
- JOHNSON, D. L. 1977. The late Quaternary climate of coastal California: evidence for an ice age refugium. *Quaternary Res.* 8:153–179.
- KEARNEY, M. S. and B. H. LUCKMAN. 1983. Holocene timberline fluctuations in Jasper National Park, Alberta. *Science* 221:261–263.

- KUTZBACH, J. E. and P. J. GUETTER. 1986. The influence of changing orbital parameters and surface boundary conditions on climate simulations for the past 18,000 years. *J. Atmosph. Sci.* 43:1726-1759.
- LAMARCHE, V. C., JR. 1978. Tree-ring evidence of past climatic variability. *Nature (London)* 276:334-338.
- MACKEY, E. M. and D. G. SULLIVAN. 1986. A 10,000 year palynological and stratigraphic record from Gabbott Lake, Alpine County, California. Ninth Annual Amer. Quaternary Assoc., Abstr. with Program 95.
- MAJOR, J. 1977. California climate in relation to vegetation. *In* M. G. Barbour and J. Major, eds., *Terrestrial vegetation of California*, p. 11-74. John Wiley and Sons, New York.
- and D. W. TAYLOR. 1977. Alpine. *In* M. G. Barbour and J. Major, eds., *Terrestrial vegetation of California*, p. 601-678. John Wiley and Sons, New York.
- MARTIN, P. S. 1963. The last 10,000 years: a fossil record of the American southwest. Univ. Arizona Press, Tucson.
- . 1984. Prehistoric overkill: the global model. *In* P. S. Martin and R. G. Klein, eds., *Quaternary extinctions, a prehistoric revolution*, p. 354-403. Univ. Arizona Press, Tucson.
- MATTHES, F. E. 1960. Reconnaissance of geomorphology and glacial geology of the San Joaquin Basin, Sierra Nevada, California. U.S. Geol. Surv. Prof. Pap. 329.
- MEHRINGER, P. J., JR. 1967. Pollen analysis of the Tule Springs site area, Nevada. *In* H. M. Wormington and D. Ellis, eds., *Pleistocene studies in southern Nevada*, p. 129-200. Nevada State Mus. Anthropology Pap. No. 13.
- MITCHELL, V. L. 1976. The regionalization of climate in the western United States. *J. Appl. Meteorol.* 15:920-927.
- MUNZ, P. A. 1959. *A California flora*. Univ. California Press, Berkeley.
- . 1968. *Supplement to a California flora*. Univ. California Press, Berkeley.
- PORTER, S. C. and G. H. DENTON. 1967. Chronology of neoglaciation in the North American Cordillera. *Amer. J. Sci.* 265:177-210.
- , K. L. PIERCE, and T. D. HAMILTON. 1983. Late Wisconsin mountain glaciation in the western United States. *In* S. C. Porter, ed., *Late-Quaternary environments of the United States*, vol. 1, p. 71-114. Univ. Minnesota Press, Minneapolis.
- PYKE, C. B. 1972. Some meteorological aspects of the seasonal distribution of precipitation in the western United States and Baja California. Univ. Calif. Water Resources Center Contrib. 139.
- RITCHIE, J. C., L. C. Cwynar, and R. W. SPEAR. 1983. Evidence from northwest Canada for an early Holocene Milankovitch thermal maximum. *Nature (London)* 305:126-128.
- SCUDERI, L. A. 1984. A dendroclimatic and geomorphic investigation of late-Holocene glaciation, southern Sierra Nevada, California. Ph.D. dissertation, Univ. California, Los Angeles.
- SELLERS, W. D. 1984. The response of a climate model to orbital variations. *In* A. Berger et al., eds., *Milankovitch and climate, understanding the response to astronomical forcing*, p. 765-788. Kluwer, Hingham, MA.
- SMITH, G. I. and F. A. STREET-PERROTT. 1983. Pluvial lakes of the western United States. *In* S. C. Porter and H. E. Wright, eds., *Late Quaternary Environments of the United States*, p. 190-212. Univ. Minnesota Press, Minneapolis.
- SPAULDING, W. G. and L. J. GRAUMLICH. 1986. The last pluvial climatic episodes in the deserts of southwestern North America. *Nature (London)* 320:441-444.
- VANCE, R. E. 1985. Pollen stratigraphy of Eaglenest Lake, northeastern Alberta. *Can. J. Earth Sci.* 23:11-20.
- WELLS, S. G., L. D. McFADDEN, and J. C. DOHRENWEND. 1987. Influence of late Quaternary climatic changes on geomorphic and pedogenic processes on a desert piedmont, eastern Mojave Desert, California. *Quaternary Res.* 27:130-146.

- WEST, G. J. 1982. Pollen analysis of sediments from Tule Lake: a record of Holocene vegetation/climatic changes in the Mendocino National Forest, California. *In* Proceedings, symposium of Holocene climate and archeology of California's coast and desert, San Diego, California, Feb. 1982. Spec. Publ., Anthropology Department, San Diego State Univ.
- . 1986. Late Pleistocene and Holocene vegetation and climate. *In* M. Basgall and W. R. Hildebrandt, principal investigators, Data recovery excavations at sites CA SHA 1176, CA SHA 1175, CA SHA 1169, and CA SHA 476, Shasta County, California, p. 2.15–2.35. Draft Report, Calif. Dept. Transportation, Redding District.
- WOOD, S. H. 1975. Holocene stratigraphy and chronology of mountain meadows, Sierra Nevada, California. Ph.D. dissertation, California Inst. Technology, Pasadena.
- WRIGHT, H. E. 1967. A square-rod piston sampler for lake sediments. *J. Sediment. Pet.* 37:975–976.

(Received 9 Apr 1987; revision accepted 25 Jan 1988.)

ANNOUNCEMENT

NEW PUBLICATION

STIEBER, M. T., A. L. KARG, M. WALKER, G. D. R. BRIDSON, H. M. BURDET, M. M. CHAUTEMPS, and T. MORUZZI-BAYO (compilers), *Catalogue of portraits of naturalists, mostly botanists, in the collections of the Hunt Institute, The Linnean Society of London, and the Conservatoire et Jardin Botaniques de la Ville de Genève*, pt. 1, *Group portraits*, Hunt Institute for Botanical Documentation, Carnegie-Mellon Univ., Pittsburgh, PA 15213, 1987, xi, 93 pp., unillus., ISBN 0-913196-50-9 (paperbound), \$9.00 (for U.S. and Canada, from preceding address; from elsewhere order from Wheldon & Wesley, Lytton Lodge, Codicote, Hitchin, Herts. SG4 8TE, England).

ANNOUNCEMENT

TWELFTH GRADUATE STUDENT MEETINGS

The California Botanical Society will sponsor the Twelfth Graduate Student Meetings on 29 October 1988 at San Jose State University.

The presentation categories (proposed research, research in progress, and finished research) allow the sharing of ideas and knowledge within the graduate student community. Awards for each of these categories will be presented at the banquet on 29 October.

For information contact Valerie Haley, Graduate Student Representative, Department of Biological Sciences, San Jose State University, San Jose, CA 95192.